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Field Distribution and Effective Height of Lightning Protection Rod with Horizontal Circular Loop – Full Model

Saša S. ILIĆ and Slavoljub R. ALEKSIĆ

1. INTRODUCTION

During a sunny summer day atmospheric electric field strength is in our region around $150\,\mathrm{V/m}$, increasing during a thunderstorm till enormous values of around $5\,\mathrm{kV/m} \div 10\,\mathrm{kV/m}$. Such an atmospheric field is practically constant in time and almost homogeneous at long distances from the earth surface. Existing objects and buildings perturb the atmospheric field, so the field distribution in urban regions is non-homogeneous and very complex.

The atmospheric field distribution around the lightning protection rod with circular loop (Fig. 1) will be presented in this paper. Based on obtained results it is possible to determine the strength of resulting electric field in the surroundings of an isolated lightning protection rod with horizontal circular loop and to construct equipotential and equienergetic contours. It is also possible to determine the effective height of the lightning protection rod installed at earth surface and to investigate the influence of the volume and shape on effective height of lightning protection rod with horizontal loop [1]. These investigations are significant because the vertical rod in galvanic connection with horizontal loop has become the Serbian standard of lightning protection, JUS N. B4. 811. The theoretical basis of vertical rod with horizontal loop as lightning protection system has been for the first time presented in 1988 at lightning protection conference in Graz [1]. At the next conference on lightning protection, in 1992, in Berlin [2], the group of Japanese explorers has experimentally confirmed the mentioned theoretical results. The experimetally results will be presented here too. In papers published up to now [3-13], all the parts of lightning protection rod with horizontal circular loop haven't been considered, that are otherwise used for fixing this lightning rod.

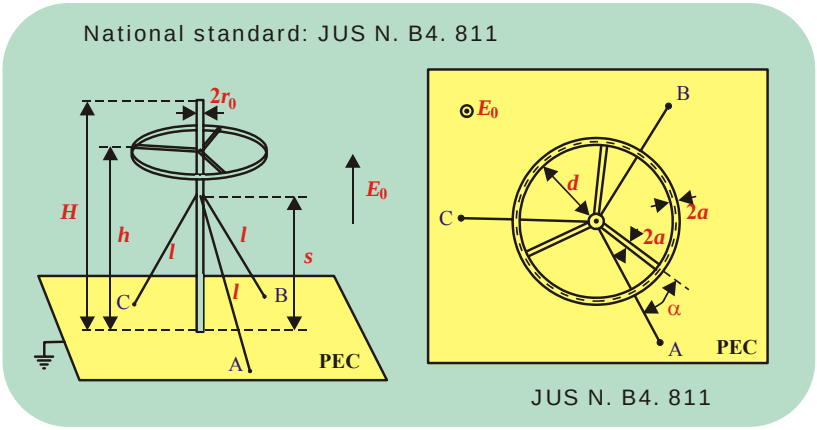


Fig. 1. *Lightning protection rod with horizontal circular loop (JUS N. B4. 811).*

2. THEORETICAL APPROACH

In order to determine electric field and potential distribution in the surroundings of the lightning protection rod with horizontal circular loop in atmospheric electric filed, point matching method and metod of segments are used. So the whole system is replaced by point equivalent unknown charges with position in centres of small segments. The upper rod basis is replaced by small spherical equivalent electrode having radius $a_\mathrm{e} = 2r_0/\pi$, where r_0 is radius of lightning protection rod. Finally, using image theorem, the potential in the field point $\mathrm{M}(x,y,z)$ can be given in the following form

$$\varphi = -E_0 z + \sum_{n=1}^{N} \frac{Q_n}{4\pi\varepsilon_0} \left(\frac{1}{\sqrt{(x-x_n)^2 + (y-y_n)^2 + (z-z_n)^2}} - \frac{1}{\sqrt{(x-x_n)^2 + (y-y_n)^2 + (z+z_n)^2}} \right) \quad (1)$$

where:

E_0 is intensity of atmospheric electric field; and

Q_n are charges and x_n, y_n, z_n coordinates of the positions of the point charges.

Boundary condition that the potential of all parts of this lightning protection rod is equal to zero is applied to equation (1). This equation can be solved numerically using point matching method, so the linear equations system is formed. After solving this system the unknowns can be determined and the necessary calculation can be performed in the standard way. So the electrical dipole moment can be written as

$$p_{\mathrm{u}} = 2\sum_{n=1}^{N} Q_n z_n \,. \tag{2}$$

In case of half spherical body of radius a_{L} at the earth surface, the electrical dipole moment is

$$p_{\mathrm{L}} = 4\pi\varepsilon_0 a_{\mathrm{L}}^3 E_0 \,. \tag{3}$$

The dipole moment of the single vertical thin rod, having circular cross- section of radius $r_{0\mathrm{eff}}$ and height H_{eff}, and placed in axial atmospheric electric field, is

$$p_{\mathrm{s}} = \frac{4\pi\varepsilon_0 H_{\mathrm{eff}}^3 E_0}{3\ln\left(2H_{\mathrm{eff}}/r_{0\mathrm{eff}}\right)} \,. \tag{4}$$

After equalizing (2) and (3) i. e. (4), using the condition $H/r_0 = H_{\mathrm{eff}}/r_{0\mathrm{eff}}$, effective height of equivalent Franclin's rod can be obtained (Fig. 2).

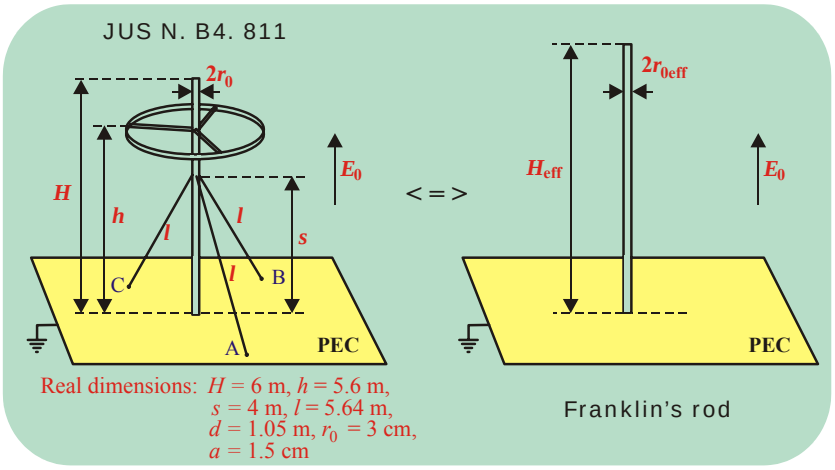
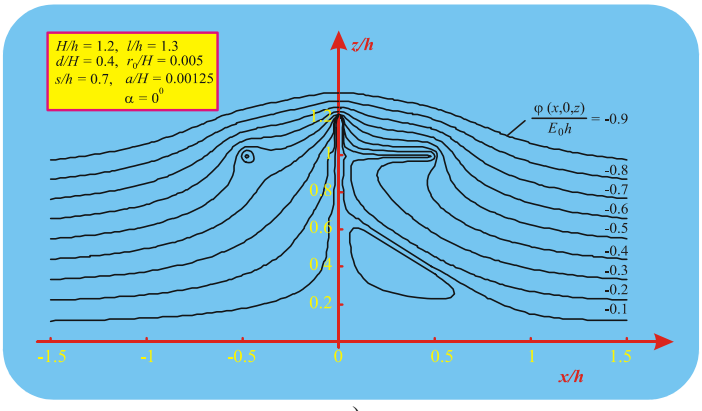


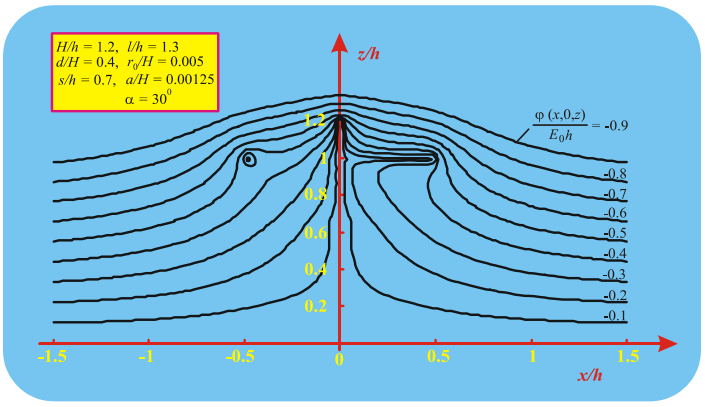
Fig. 2. *Equivalent Franklin's rod.*

3. NUMERICAL RESULTS

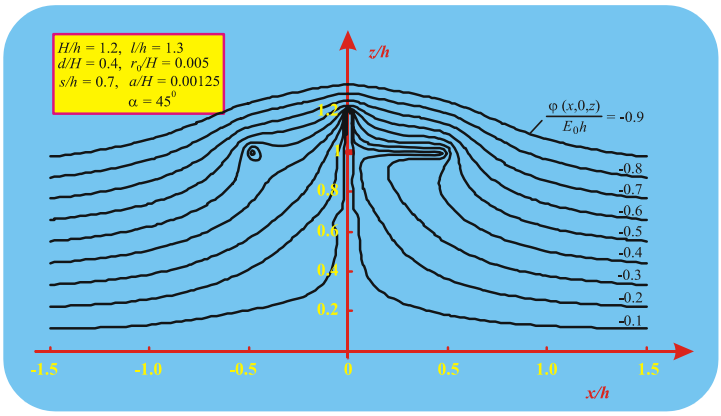
All results for field distribution and effective height are presented graphically.



a)

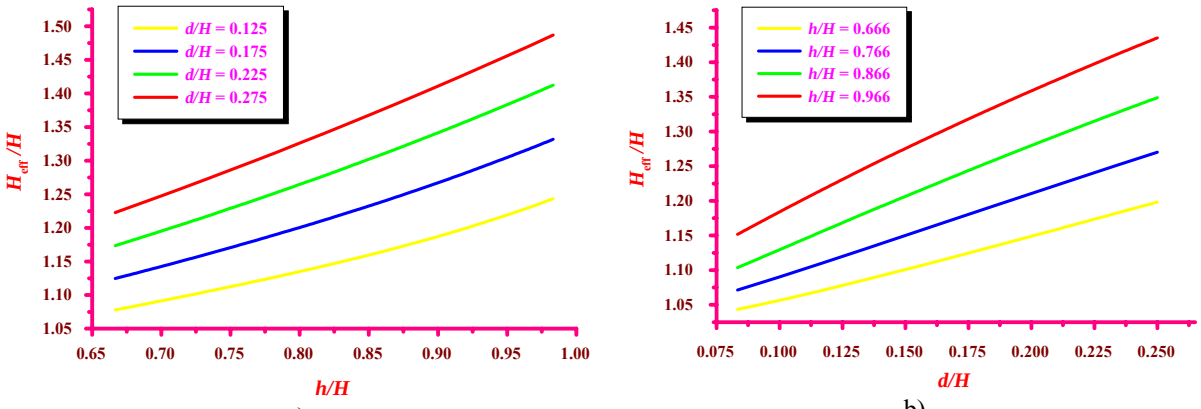


b)



c)

Fig. 3. *Field distribution near lightning protection rod (JUS N. B4. 811) versus different parameter* α.



a) b)

Fig. 4. *Effective height of lightning protection rod (JUS N. B4. 811) versus parameters* h/H *and* d/H.

4. CONCLUSION

Theoretical research has a numerical background and the results for electric field distribution and effective height are presented graphically. Effective height for real dimensions of lightning protection rod with horizontal circular loop has value $H_{\text{eff}} = 1.3H$. Effective height is one very important parameter for defining protection zone versus protection level of proposed lightning protection rod. The rod is tested in high voltage laboratory (Japan), and experimental results for effective height have very good agreement with theoretically obtained results.

Fig. 5. *Photos of installed lightning protection rod (JUS N. B4. 811).*

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